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ANALYSIS OF AND MODELING FOR EMERGENCY MEDICAL SERVICES FACILITY LOCATION FOR ROAD ACCIDENTS ON HIGHWAY

RAMKRISHNA S. BHARSAKADE, ONKAR S. KULKARNI,
ADITYA S. AFLE & MAITREYEE S. KULKARNI
Vishwakarma Institute of Technology, Pune

ABSTRACT

This paper analyses the accident-prone regions along the 94.5km stretch of Mumbai-Pune express highway to determine optimal base locations for dispatching Emergency Medical Services (EMS). The study was driven by an increasing concern over the rise in accident fatalities on the expressway, and the alarming inadequacy of ambulance services. Our research aims to determine the optimal emergency medical service (EMS) facility locations to address the needs generated by accidents on expressways with heavy flowing traffic. Expressways present the unique problem of being isolated from hospitals and trauma centers located within cities, as well as practical constraints in turning vehicles around due to unidirectional heavy flow of traffic. We have used the mean shift algorithm of machine learning to determine clusters along with their centers. We further employed the minimax facility location model for rectilinear distances to determine a second base location within the primary clusters. The purpose of the secondary base locations is to supplement the primary EMS locations and distribute the load to ensure that the dispatched ambulances reach the accident spot in 8 minutes. The proposed model combines a traditional approach with a machine learning algorithm to produce faster output.

KEYWORDS: Accident-Prone Regions, Unidirectional Heavy Flow.& Produce Faster Output

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Original Article

I. INTRODUCTION

Road accidents in India are listed as among the highest in the world, according to a Global Status Report on road safety published by the World Health Organization (WHO). Over 135,000 traffic collision related deaths occur every year in India, as revealed by a report from the National Crime Records Bureau (NCRB) (Traffic collisions in india). The major contributing factors that caused road accidents were over speeding, driving under the influence of alcohol and not using safety equipment such as helmets and seat belts, as published by the World Health Organization's "Global Status report on Road Safety."Highways in the country constitute a major portion of the road traffic. Naturally, a large number of accidents take place on the highways. This paper focuses on the examination of one such route of heavy traffic flow- the Mumbai Pune Expressway.

The Mumbai-Pune Expressway is a six-lane, access controlled tolled highway that stretches across a distance of 94.5 km. It connects Mumbai, the commercial capital of the state of Maharashtra and Pune, the educational and IT hub. Considered to be one of the busiest roads of India, the construction of this ambitious project was undertaken by MSRDC after the Government of Maharashtra handed over the work to them in March 1997 on Build-Operate-Transfer basis. The initial sections opened in 2000, and from April 2002, a fully operational route was opened to the traffic (Mumbai-Pune Expressway). Ever since, it has served as an alternative

to the old Mumbai-Pune highway (NH 48) and has promoted a reduction in the time travel between the two cities.

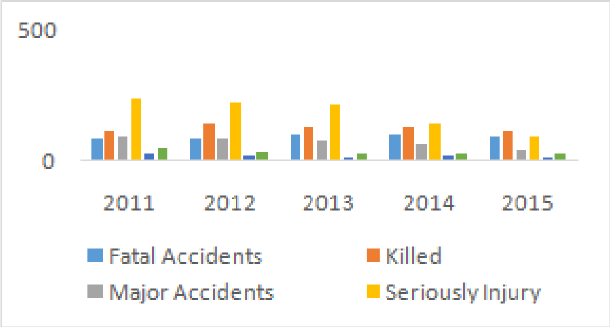

Figure 1: Accident Rates 2011-2015

Being a perpetually engaged road, the Expressway has been a witness to several traffic crashes, injuries and fatalities since its inception in 2002. A number of factors have contributed to this rise in the frequency of accidents, and they have been broadly classified into Human, Vehicle and Infrastructure related factors. A study of 100 accident cases on the Expressway conducted by researchers at JPRI from the period 1st April 2016, to 31st October 2016 revealed that Human factors such as over speeding, fatigue and drowsiness experienced by the driver, inattention of the driver and improper change of lane and accounted for 96% of the accidents. Infrastructural issues such as inadequate warning of parked vehicles, slippery road surfaces and sharp curvature closed in at the second spot with 14%. Inherent problems of the vehicles in question, such as defective tyres and absence of reflectors had no more than 8% role to play in the accidents. (JPRESEARCH, 2016)

The increase in the number of accidents is not the only concern. According to road safety experts, a large number of accidents are not even reported. This implies that the actual number of accident fatalities might be higher than are documented. Secondly, there is a serious dearth of well-equipped ambulance services, tertiary care hospitals and trauma centers that can cater to the needs of accident victims in time to save their life. A critical situation such as that of a road accident demands immediate medical attention, the lack thereof leading to death or severe damage to the victim.

Emergency Medical Systems form an integral part of public health-care services. A typical EMS consists of a set of Emergency Response Vehicles, ERVs that provide timely care to patients in need of immediate attention, or transfer them to the nearest trauma center. In an EMS, two factors are taken into consideration: a set of base stations are strategically placed throughout the identified region and afixed number of ERVs are determined to be placed at each base location. Upon request, an ambulance placed closest to the accident spot is dispatched from the base location to assist the victim or take him to the nearest medical facility. After delivering the victim, the ambulance returns to its original base location. (Supriyo Ghosh, Pradeep Varakantham)

Nigdi based private hospital- ‘Lokmanya’, initiated the establishment of Emergency Medical Services (EMS) along the stretch of the Mumbai-Pune Expressway in the year 2002. By strategically placing six ambulances along the expressway as well as the old highway, the hospital aims at achieving the goal of reduced road accident morbidity and mortality and providing comprehensive trauma care. These sustained efforts have resulted into effective reduction in RTA mortality rate to.003304 on Mumbai – Pune express highways.

These sustained efforts, however, are not sufficient to tackle the increasing demand for ambulance services on the expressway where accidents take place every day in widely spread out regions. Considering an absence of medical facilities and functioning trauma centers along the expressway, it is vital that ambulances equipped with lifesaving facilities and trained paramedics be employed in sufficient numbers to reduce mortality rates.

This paper is an attempt at proposing a model to locate an optimal number of EMS base locations along the 94.5 km stretch of highway so that the ambulance can achieve a response time of 8 minutes to a victim’s call for help. It employs the Mean shift algorithm, a machine learning algorithm, to determine the number of clusters and their respective centers for a given set of data points. Further, it operates the minimax location model on individual clusters to locate another centroid that serves to act as a supplementary base location along with the previously identified base location for each cluster.

II. LITERATURE REVIEW

The problem of EMS facility location has been extensively studies due to its critical nature, practical importance and direct engagement with human life. The methodologies used to locate ambulances in EMSs are broadly classified into two main categories: facility location models and probabilistic models that use spatial queuing theory or simulation. The objective of the facility location models is to improve the quality of service by reducing the maximum response time. The maximum response time is a factor that determines the maximum coverage distance and maximum coverage area for an ambulance. Incidentswithin the coverage area of an ambulance are considered well served. However, if an incident lies outside the coverage area, then it is not well served due to an increase in the time of response. (Carolina Castañeda P. a, 2016). Early models, like the Set CoveringLocation Problem (SCLP), are based on this principle. In this model, the objective is to minimize the number of ambulances needed tocover all demand points spread over a region (C. Toregas, 1971). A generalization for locating several new facilities, called the "p-center" problem, has been considered by Christofides and Viola (Christofides, 1971), Minieka (Minieka, 1970), Garfinkel et al (Garfinkel, Neebe, & Rao, 1974)and Handler (Handler, 1974). Multi-facilityminimax problems on tree networks are studied by Dearing, Francis, and Lowe (Dearing, Francis, & Lowe, Convex location problems on tree networks, 1976).

The Maximal Covering Location Problem (MCLP) (Church & ReVelle, 1974)aims to select the locations of a given number of serversthat maximize the demand within the target service time (i.e., the covered demand). Although SCLP and MCLP have been applied successfully to locateambulances, these early models ignore the unavailability of theambulances while they are attending an emergency. Recognizing these limitations, there are probabilistic facility location models that seek to include the busyness of the system as well. Daskin (Daskin, A maximum expected covering location model: formulation,properties and heuristic solution, 1983)introduces the Maximum Expected Coverage LocationProblem (MEXCLP) that maximizes the demand covered but weightedby the service availability that each demand zone observes. Serviceavailability is calculated through the global estimation of the averagebusyness of the system and considers the number of ambulanceslocated within the maximum response time for each demand zone. Ambulance location models have been applied using real datafrom their beginnings. For instance, in Austin (Texas), Eaton et al. (Eaton, Daskin, Simmons, & Bulloch, 1985)describe the application of an MCLP-like model for the location of ambulances, and Daskin and Stern (Daskin & Stern, 1981) introduced a hierarchicalset covering model that first minimizes the number of ambulancesrequired to cover all the zones in a given time and then maximizesthe number of zones covered by more than one ambulance. Likewise, Rajagopalan and Saydam (Rajagopalan & Saydam, 2009)apply two minimum

expected response models to the EMS fromMecklenburg County (USA): the first one uses the expected coverageand the second one uses the available coverage. Some studies, like (Salman & Gül, 2014) address the EMS response to mass casualtyincidents that require a course of action on a large scale. We have focused our study on traffic accidents on the expressway. EMS deployed for highways and other such tracks are required to be well equipped to handle a variety of emergency situations- ranging from cardiac arrest and childbirth, to traffic crashes. This is because there are no other set of healthcare options available for people in the middle of the road.

III. RESEARCH

Overview

Our study focuses on locating dispatch spots for Emergency medical services on the Mumbai-Pune expressway at optimal locations so as to achieve quality service and response time. We identified 40 accident prone zones on the stretch of the expressway, starting at Kalamboli (just before Panvel) and ending at Dehu Road (just before Pune), navigating through six interchanges: Shedung, Chowk, Khalapur, Lonavala, Kusgaon and Talegaon. The data for accident prone regions was obtained from various sources: Newspaper articles, JPRI case-study (JPRESEARCH, 2016). We used GoogleMaps to determine the coordinates of the accident-prone regions. With the number of accidents only increasing by the day, quick responsive EMS facilities are necessary on the expressway. The lack of any hospital or trauma centeralong the route makes the existence of fully equipped ambulances and paramedic services essential.

The main mathematical model that we have used to dispatch EMS services on the Mumbai-Pune expressway is the mean shift algorithm as presented in “Clustering Methods” (Rokach, Lior, & Maimon, 2005). Mean shift algorithm provides the number of clusters and their corresponding centroids that serve to act as primary base locations for ambulances. In our study, the algorithm yielded a total of 6 clusters spaced out roughly at intervals of 15km. A further application of the minimax facility location model using rectilinear distances on each cluster yields another centroid per cluster that acts as a second ambulance dispatch location. The minimax location model in our case had to be applied only to cluster 0 as the density of accident spots in that cluster is higher than all the other clusters. The average speed of an ambulance on the expressway is taken as 80km/hr along most stretches (JPRI report). According to our data as well as the information for bandwidth specified for the mean shift algorithm, the maximum distance of the farthest accident spot in cluster number 0 is around 23km. With an average speed of 80km/hr, it is not possible to achieve the response time of 8 minutes. Hence, a second base location within the same cluster is determined using minimax location model that can aid the primary facility in sharing the work distribution and effectively enhance the quality of service. Another significance of identifying second base locations is that they can tackle the problem of the presence of a limited number of access points on expressways. Having two location spots means that ambulances can be placed on either side of the median strip so as to facilitate quick response for both sides of the traffic flow. Our model assigns equal weight to each and every data point, as every accident is considered to be equally important. The implementation of mean shift algorithm has been carried out in Python, while the minimax model was solved using MS Excel.

Minimax Facility Location for Rectilinear Distances

Minimax location problems have received considerable attention in the literature as models for locating facilities that are to provide emergency or convenient service to a set of existing facilities. In most of these problems there is given a set of existing facilities whose locations are represented as points in some space, and new facility locations are also to be specified as points in that space. A distance function is chosen to represent the travel di stance between the new and

existing facility locations. The minimax objective is to locate the newfacilities so that the maximum distance, or a function of di stance, between the new and existing facility locations is minimized (Dearing, Minimax Location Problems With Nonlinear Costs, 1977), (Panneerselvam, 2013)

Minimax Model

Min {z(x,y) = Max [|x – ai | + |y – bi |]} i = 1,…,m

Min {z(x,y) = Max [|x–a1|+|y–b1|,|x–a2|+|y–b2|,…,|x–am |+|y–bm|]}

c1 = min (ai+bi-hi)

c2 = max (ai+bi+hi)

c3 = min (- ai+bi-hi)

c4 = max (- ai+bi+hi)

c5 = max (c2-c1, c4-c3)

Optimal Solution:

Line joining

A(x*, y*) = ½ (c1 - c3, c1+c3+c5)

&

B(x*, y*) = ½ (c2 - c4, c2 + c4 - c5)

Minimum Longest Distance, z* = c5 / 2

Mean Shift Algorithm

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). It is a main task of exploratory data mining, and a common technique for statistical data analysis, used in many fields, including machine learning (Rokach, Lior, & Maimon, 2005), (Kaufman & Rousseeuw, 1990).

Applications of Mean Shift Algorithm

Consider a set of points in two-dimensional space. Assume a circular window centered at C and having radius r as the kernel. Mean shift is a hill climbing algorithm which involves shifting this kernel iteratively to a higher density region until convergence. Every shift is defined by a mean shift vector. The mean shift vector always points toward the direction of the maximum increase in the density. At every iteration the kernel is shifted to the centroid or the mean of the points within it. The method of calculating this mean depends on the choice of the kernel. In this case if a Gaussian kernel is chosen instead of a flat kernel, then every point will first be assigned a weight which will decay exponentially as the distance from the kernel's center increases. At convergence, there will be no direction at which a shift can accommodate more points inside the kernel. (Arslan, Constable, & Kent, 1993).

Logic behind Python's "Scikitlearn" Library for Mean Shift Algorithm

A function N(x) to determine what are the neighbours of a point x ∈ X. The neighbouring points are the points within a certain distance. The distance metric is usually Euclidean Distance.

A kernel K(d) to use in Mean shift. K is usually a Gaussian Kernel, and d is the distance between two data points.

Now, with the above, this is the Mean shift algorithm for a set of data points X:

For each data point x ∈ X, find the neighbouring points N(x) of x.

For each data point x ∈ X, calculate the mean shift m(x) from this equation:

$$n(x) = \frac{\sum x_i \in N(x)\ K\ (x_i - x) x_i}{\sum x_i \in N(x)\ K\ (x_i - x)}$$

(Fukunaga & Hostetler, 1975)

For each data point x ∈ X, update x ← m(x).

Repeat 1. for n_iteations or until the points are almost not moving or not moving.

(sklearn.cluster.MeanShift, n.d.), (meanshift-algorithm-for-the-rest-of-us-python, n.d.)

IV. RESULTS

Data Analysis

Using the mean shift algorithm, we obtained a total of 6 clusters with their corresponding centroids. The coordinates that are obtained correspond to the following places along the Mumbai-Pune expressway:

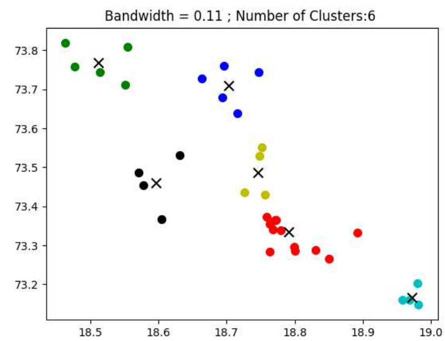

Figure 2: Distribution of Clusters

Figure: Scatter of data points, clusters and centroids

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============= RESTART: C:\Python36\Research_Paper_Clustering.py =============
<class 'numpy.ndarray'>
[0 5 0 5 0 3 3 1 5 0 2 4 0 4 1 0 0 0 1 1 4 1 3 4 2 2 0 5 0 0 3 0 2 2 0]
[[ 18.79100521   73.33379914]
 [ 18.5116958    73.7690498 ]
 [ 18.7032282    73.7105594 ]
 [ 18.972592     73.16713525]
 [ 18.59626525   73.4597005 ]
 [ 18.745926     73.4865955 ]]
Number of Estimated clusters: 6
```

Figure 3: Final Cluster Centroid Co-Ordinates

Final points	P1	18.850324	73.264607
	P2	18.850324	73.264607

Figure 4: Final Minimax Calculations for Cluster 0.

The corresponding locations for the centroids are:

- Yashwant Nagar, Khopoli
- BavdhanBudruk
- Somatane
- Ariwali, Panvel Bypass
- Lonavala center.
- Malavli

The second point for cluster 0 is near Isambe village, 6 km's from Khalapur.

Satellite Map Images of Result Co-Ordinate Locations

Figure 5: Yashwant Nagar

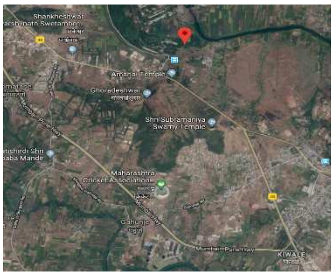

Figure 6: Somatane

Figure 7: Malavli

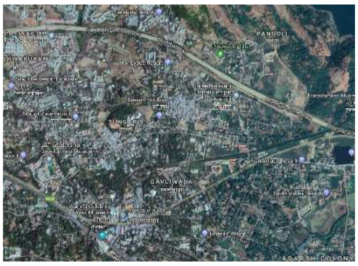

Figure 8: Lonavala center

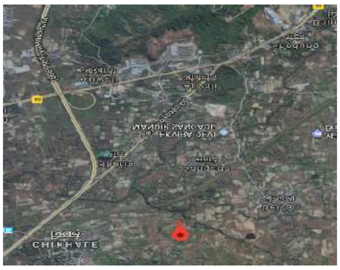

Figure 9: Panvel Bypass

Figure 10: Bavdhan Budruk

Figure 11: Isambe, Khalapur

V. CONCLUSIONS

This paper attempts to propose a model for location of emergency medical services by combining traditional facility location model (minimax) with a machine learning algorithm (mean shift). An ambulance works in four stages, viz. 1) Reach the accident spot upon request, 2) Transfer the victim/s inside the ambulance, 3) Take the victim to the nearest medical facility and 4) Return to its base location. The results reveal that although the base locations have been optimally determined,it is equally important to take other factors into account such as busyness of the system, unavailability of an ambulance when it is away to drop off a victim as well as practical limitations that are posed by distances between two locations being neither rectilinear nor Euclidean. Further, one needs to increase the size of fleet of ambulances according to the density of accidents in that region. Multiple ambulances deployed from the same base location can be far more effective and efficient than locating multiple base locations.

Road safety receives inadequate attention at the central, state and local government levels. Since the problem of traffic accidents does fall under the domain of any particular agency, we see a lack of initiative from all the three agencies of governance to address this issue. The situation needs to be addressed and handled sincerely. Urban planning and design of road networks, enforcement of strict road safety legislations and traffic safety awareness needs to be developed among the public to tackle this issue. Relevant, clean and consistent data about rod accidents has to be collected so that statistical and operations research tools can be used to analyze them.

Further research can include models that address the above mentioned limitations. Rectilinear distances can be included to give more accurate results in place of Euclidean distances. Simulation models, heuristics models that give near optimum solutions as well as spatial queuing models can be employed to improve and refine the results obtained by conventional location models.

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